Design of a High Tension Transmission System

A. L. Kubitz

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Design of a High Tension Transmission System.

A THESIS

PRESENTED BY

Alfred L. Kubitz.

TO THE

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OF

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FOR THE DEGREE OF

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Design of a High Tension Transmission System.

In the treatment of this subject an attempt shall be made to present in a general way the requirements of the various pieces of apparatus, and the most recent practice in the construction of a transmission line, and to apply the same to the specific case of a system to be built between Chippewa Falls and Minneapolis. Owing to lack of actual data in most of the instances, assumptions will be made as to conditions as they probably exist.

General description.

7500 K. W., three phase, star connected, 25 cycle, 60,000 volt power is obtainable at the high tension bus bars of the generating station at Chippewa Falls. This power is to be transmitted over a distance of 160 miles to the high tension bus bars of the distributing station at Minneapolis.

The line should be a double circuit system, so that in case of trouble on one circuit, the power can be shifted on to the reserve circuit. This will insure continuity of service, which is of prime importance.

Line drop, current and power factor.

For a system of this kind 90 per cent and 10 per cent seem to be approximately the average values of power factor and drop of voltage, respectively. With these respective values decided upon, the line current can be calculated from the formula

$$P = \sqrt{3}\ E\ I\ \cos\theta$$

in which $P =$ the power in watts

$E =$ voltage between two conductors

$I =$ current in each conductor

$\cos\theta =$ power factor of the system.

Substitution of the respective values in the formula gives

$$7500000 = 3 \times 60000 \times .90 \times I$$

$$\text{or } I = 80.5 \text{ Amperes.}$$

This is the value of the normal current in each conductor.

The line drop of this system, as stated above, is 10 per cent or

$$60000 \times .10 = 6000 \text{ volts.}$$

Let $Z =$ the impedance of the circuit. Then $I\,Z =$ the line drop, in which I is the value of the current in line.

Let $R =$ ohmic resistance of the circuit. Then $\frac{R}{Z} =$ power factor of the system

$$\text{or } \frac{R}{Z} = \cos$$

$$\therefore Z = \frac{R}{\cos}$$

$$\therefore \frac{I\,R}{\cos} = \text{line drop.}$$

or

or by substitution

$$\frac{80.5 \times R}{.9} = 6000$$

which gives

$$R = 67.08 \text{ ohms.}$$

This is the resistance of one loop; therefore the resistance of one conductor throughout the entire length of the system should be

$$67.08 \div 2 = 33.54 \text{ ohms.}$$

or $\frac{33.54 \times 1000}{160 \times 5280} = .0397$ ohms per 1000 ft.

Conductor.

For transmission purposes steel, iron, copper, and aluminum conductors only are used. Steel and iron are used in very few instances. The chief materials used are copper and aluminum, each of which has its advantages and disadvantages over the other. The greatest disadvantages of copper are its heaviness and high price.

In comparing aluminum and copper one finds that :

1. Aluminum is stronger in reference to its weight for the same conductivities than copper, but at the same time it is materially larger and the resultant wind stress on the line greater.

2. Aluminum gathers much less sleet than copper.

3. It costs less to string aluminum wires on account of its lighter weight; but on the other hand care must be taken in stringing this wire in rough country on account of its softness; stones or rough places causing considerable abrasion where it is dragged along the ground.

4. Mechanical and splice joints as now used on aluminum wire are entirely satisfactory without the use of solder.

5. The wires on an aluminum pole line should be spaced further apart than copper wires are, in order to avoid burning

off the wire in case of a short circuit. The melting point of aluminum is much lower than that of copper and the damage from a prolonged arc is therefore greater.

6.

For the same length of span the strain on the insulator pins and on the tower is greater for copper than for aluminum, and this is an important feature when long spans are used.

In high tension work the wire is invariably uninsulated, since it is believed that no insulation is a true protection and the frank nakedness of the bare wire is a warning, and in consequence a safeguard to those who are compelled to work near the line. Preference between aluminum and copper is chiefly a question of economics.

After the resistance of the conductor has been determined, the next step is to find the proper sized wire of either metal in question. In looking over tables in handbooks one finds the following standard sized conductors to most nearly approach the requirement of having a resistance of .0397 ohms per 1000 ft.

	Copper (Roebling)	Aluminum (Pittsburg Reduction Co.)
Diam.	.63 inches	.772 inches
Area	300000 C M	450000 C M = .3545 sq. in.
Resistance	.03502 ohms per 1000 ft.	.037170 ohms per 1000 ft.
Weight	915 lbs. per 1000 ft.	414 lbs. per 1000 ft.
Elastic Limit		4950 lbs. or 14000 lbs. per sq. in.

	Copper (Roebling)	Aluminum (Pittsburg Reduction Co.)
Ultimate Strength		9190 lbs. or 26000 lbs. per sq.in.

Above properties at 70° Fahr. in each case.

From this it is seen that either

160 x 5.280 x 915 = 773000 lbs. of copper or

160 x 5.280 x 414 = 350000 lbs. of aluminum

will be used for the length of one conductor.

Taking the price of copper at 28 cents per pound and that of aluminum at 50 cents, there will result a total cost of

773000 x 6 x .28 = $1,297, 640 for copper conductors or

350000 x 6 x .50 = $1,050, 000 for those of aluminum. Therefore there will be a saving of $247,640 in the use of aluminum over that of copper.

It remains now to be determined whether or not the aluminum conductor will be able to withstand all strains which it is liable to come under. These strains are chiefly due to (1) the weight of the wire itself, (2) the weight of snow or sleet forming upon it, and (3) the effect of wind pressure. The strains due to all three of these causes increase with the length of the span and size of conductor. The effect of wind pressure depends also upon the velocity of the wind. The effect of wind velocity upon the conductor has been experimented upon by Mr. H. W. Buck, and he derived the following equation as showing the relation between wind velocity and

resulting pressure upon surfaces of stranded conductors:

$$P = .0025\ V^2$$

where $P =$ pressure in pounds per square foot of projected cable area and $V =$ actual wind velocity (not indicated velocity) in miles per hour.

The highest wind velocity which may occur between Minneapolis and Chippewa Falls is approximately about 60 mis. per hr. Applying this to the above equation gives

$$.0025\ V^2 = P = .0025 \times 3600 = 9 \text{ lbs. per sq. ft.}$$

of projected cable area.

T There has never been any data recorded as to the formation of ice on wires. It does not seem to be the experience of engineers that sleet forms on high voltage lines, and sleet certainly would not form on the lines during a high wind. However, to be on the safe side, it is well to make an allowance for this factor.

But before mechanical strains can be calculated, the length of wire in the span and its deflection must be determined. To do this use will be made of a series of equations recommended by Mr. P. O. Blackwell in a paper presented before the American Institute of Electrical Engineers in June, 1904.

Let $D =$ deflection in feet.

$S =$ length of span in feet.

$W =$ total (including sleet and wind) weight in pounds per foot length of cable.

$T =$ stress allowed in cable in pounds.

$L =$ length of cable cold.

L_o = length of cable without stress.

F = stress in pounds per square inch permitted in cable.

E = modulus of elasticity.

L_H = length of cable hot.

C = coefficient of linear expansion.

B = maximum rise in temperature, in degrees Fahrenheit.

A = cross sectional area of cable in square inches.

R_m = tension at the middle of the wire.

R_E = " " " ends " " " .

then

$$D_1 = \frac{S^2 \times W}{8\ T}$$

$$L_1 = S + \frac{8D_1}{3S}$$

$$L_o = \frac{L}{1 + \frac{F}{E}}$$

$$L_H = L_o\ (1 + C\ B)$$

$$D^3 + \frac{2S}{8}\ (S - L_H)\ D = \frac{3\ S^3\ L_H W}{64\ E\ A}$$

$$R_m = \frac{L^2 - 4\ D^2}{8D}\ W$$

$$R_E = \sqrt{(R_m)^2 + \left(\frac{L\ W}{2}\right)^2}$$

By substitution in the above equations the following results are obtained:

$$D_1 = \frac{(500)^2 \times 1}{8 \times 3465} = 9 \text{ Ft.}$$

$$L_1 = 500 + \frac{8 \times 81}{3 \times 500} = 500.43$$

$$L_0 = \frac{500.43}{1 + \frac{9800}{9000000}} = 499.88$$

$$L_H = 499.88 \left[1 + (.0000128 \times 150) \right] = 500.84$$

$$D^3 + \frac{3 \times 500}{8} (500 - 500.84) D = \frac{3 \times (500)^3 \times 500.84 \times 1}{64 \times 9000000 \times .354}$$

or $D = 13$ ft.

$$L = 500 + \frac{8 \times (13)}{3 \times 500} = 500.9 \text{ ft.}$$

$$R_m = \frac{(500.9) - 4(13)^2}{8 \times (13)} \times 1 = 2406 \text{ lbs.}$$

$$R_E = \sqrt{(2406)^2 + (250.2)^2} = 2419 \text{ lbs.}$$

It will be noted in the above calculations that the total weight of conductor was taken as one pound per lineal foot. This value was obtained in the following manner: The metal itself weighs .414 lbs per foot, then there is a wind pressure of

$$\frac{.772 \times 9 \times 1}{12} = .6 \text{ lbs. per foot length}$$

which gives a resultant of

$$\sqrt{(.414)^2 + (.6)^2} = .72 \text{ lbs. per foot}$$

and then allowing .28 pound for the formation of sleet upon the wire gives a total weight of

$$.72 + .28 = 1 \text{ lb. per foot of conductor.}$$

Also, the allowable stress used was only 70 per cent of the elastic limit

$$\text{or} \quad .70 \times 4950 = 3465 \text{ lbs.}$$

which is equivalent to

$$14000 \times .7 = 9800 \text{ lbs. per sq. in.}$$

This gives a factor of safety of

$$26000 \div 9800 = 2.6$$

In looking over the results of above calculations one sees that the maximun tension which the cable is liable to undergo is lower than the allowable stress; consequently, this aluminum cable is satisfactory as to its mechanical properties. Therefore, since this stranded aluminum cable is satisfactory both mechanically and electrically, it will be used on this system.

Span and Sag.

In the previous calculation a 500 ft. span was used. This has proven itself to be a very satisfactory one and is now in common use. Therefore, it will be used on this system. The sag of the wire has been calculated to be 13 feet. This value seems a little large as compared to that indicated by curves of span and sag, but this discrepancy is

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due to the fact that the allowable stress was reduced to 70 per cent of the elastic limit.

Insulators.

The requirements of a high tension insulator may be enumerated as follows:

1, The material must have a high dielectric strength so that it will be strong enough to resist being punctured by the current. In order to fulfill this requirement the material must be homogeneous, continuous, and compact.

2, There must be sufficient resistance over the surface to avoid conduction or leakage of current.

3, The distance around the insulator between the wire and support must be sufficient to prevent the current from arcing.

4, Its contour must be such that there will be unexposed surfaces which will not get wet or accumulate dirt, salt, etc., as these materials are conducive to leakage and tend to lessen the arcing distance.

5, The shape and arrangement of the petticoats should be such that the electrostatic capacity of the insulator will be small.

6, The internal heat losses from conduction and hysteresis should not be such as appreciably to heat the insulator.

7,
It should have sufficient strength to resist all mechanical strains which it may have to withstand.

8
It should be absolutely non-absorbent. The best porcelain shows a polished fracture like glass.

The type of insulator to be used on this transmission system is shown on Plate I. It is of the four-petticoat type and made of brown glazed porcelain. The parts are cemented together with Portland cement. This type of insulator is of recent design and is giving very satisfactory results. The power wire should be run through the top groove excepting in cases where a turn is to be made, in which case the wire should be run around the side groove. The wire is to be fastened to the insulator in such a manner that if a break occurs within a span the power wire will be permitted to move over the insulator until it comes to rest. This can be accomplished by using a tie-wire of only such limited strength that if the break occurs the strain will be so great as to break the tie wire and release the line wire from the insulator. This will permit the dead end strain to distribute and take care of itself, instead of being thrown all together upon one tower. The feasibility of this construction is that it will permit of lighter tower construction. Since so low a value for permissable strain and comparatively high value for factor of safety had been used in the previous calculations, it is very improbable that the wire will break often and this would bring the annual expense of reconstruction at such breaks to a very

low value. Therefore, it will be cheaper to permit the wire to move over the insulators in case of a break than to permit the whole dead end strain to be thrown upon one tower alone and consequent necessity of heavier tower construction.

Insulator pins.

The requirements of an insulator pin are to resist all mechanical strains to which it may become subjected and to resist the effects of leakage currents upon it. Wooden pins are more or less affected by the leakage currents. These currents have a destructive effect upon the wooden pins. The degree of this effect varies with different conditions. It depends upon the locality and also upon the wood. Iron pins are not at all affected by leakage currents and also possess greater mechanical strength.

Plate II shows the insulator pin which is to be used on the present system. They are to be made of maleable iron and are to be fastened to the supporting arm by four 5/8 inch bolts.

The insulators are to be fastened to the pin by means of a lead cap which is cast on the top of the pin. One inch from the top the pin has a groove 1 inch wide and 1/8 inch deep around its circumference. This groove is to provide a means of holding the lead cap to the pin. The cap is threaded and the insulator screwed on. This provides a very satisfactory and efficient means of fastening the insulator to the pin. This form of pin gives great convenience in install-

ing .

Distance between wires.

According to common practice the distance between wires shall be 6 ft. 6 in.

Towers.

Since this line is not to be a temporary system, steel towers will be used to support the cables. These towers have several advantages over wooden poles which may be enumerated as follows:

1. They permit the use of longer spans and thus lessen the number of insulators.

2. They are fireproof and durable and readily admit of such constructions which would be impractical with wood.

3. The wires may be spaced further apart and thus lessen danger of short circuiting.

4. Insulators may be made larger and better both mechanically and electrically.

5. They offer a more or less good lightning path to ground which helps to prevent injury to connected appartus, and themselves remain unaffected by the stroke.

The most economical tower construction is one in which the spread of the legs at the base is equal to abaut 1/3 to 1/4 of the height. Where two or more circuits are supported

the length of the crossarm is so great as to require two points of support instead of one as in the single circuit tower. The tower then can be made with a width at the top approximating that at the bottom. A heavy galvanizing coating on the towers appears to be an effective protection against rusting and avoids the expense of painting. The tower is subjected to strains transferred to it from the cable , and in addition must be able to resist all wind pressures which might be exerted against it.

The type of tower which is to be used on this transmission system is shown on Plate III. It has been recommended to be of a very economical and substantial design. The towers shall be set 5 ft. in the ground, and each leg is to be surrounded by cement grouting to prevent corrosion. A clearance of 25 ft. is to be allowed between the ground and lowest wire. There is to be a telephone circuit strung 6 ft. below the lowest power wire. This will require a height of

$$25 + 6 + 13 = 45 \text{ ft.}$$

from the ground to the cross arm or

$$45 + 5 = 50 \text{ ft.}$$

from the bottom of one leg to the cross arm. The top wire of the triangle is to be supported by a three-inch wrought iron pipe screwed to the top of the framework. The insulator pin is to be supported by a cap fastened over the end of this pipe. Each tower must be able to bear a total horizontal strain of

$$6 \times 500.9 \times 1 = 3006 \text{ lbs.}$$

at the top. It must be thoroughly galvanized by the hot process

after all the work in its manufacture has been completed.

Among these towers must also be considered one which is to be used where a turn must be made in the line. A turn of 90° will only be considered . The tower to be used for such a turn is shown on Plates IV and V. Plate V shows the top view of the tower. The heavy dots indicate the positions of the insulators and the arrows indicate the path of the conductors. The requirements for this towerare the same as those of the others excepting that in this case the strains are only 90 apart;whereas, in the other cases they are 180 apart. This gives a resultant of

$$3006 \times \sec. 45^\circ = 3006 \times \sqrt{2} = 4239 \text{ lbs.}$$

acting in the direction of a line bisecting the angle formed by the turn. The legs of this tower are to be imbedded in a concrete foundation.

For the dead ends at the generating and distributing stations, the line should be supported by a tower like the one just described. But in this case the wires shall pass straight across the top and each one shall be supported by two insulators.

Telephone system.

The telephone circuit should be stretched along the system 6 feet below the lower power wires. It is to consist of number 10 B. and S., hard drawn copper wire. One half of the circuit is to be run along each side of the tower placed on insulators supported on short arms, as shown on Plate III.

The insulators must be able to withstand an electrostatic strain of 20,000 volts. Telephones are to be bridged across the circuit at points about two miles apart in suitable booths built on the towers about 5 ft. above the ground. Provision should be made so that the user is well insulated from the ground. The ordinary telephone lightning arrester is an undesireable and unsafe piece of apparatus for use on this system. Arresters should be installed on this telephone circuit similar to those used on lighting circuits. The telephone wires shall be transposed 10 times per mile at equidistant points. Lightning arresters shall be installed with each telephone. The method of connection is shown in diagram on Plate VI. There shall be short air gaps provided across the line, and also between the ground and the telephone itself. The repeating coils should be insulated for 5000 volts. This system has been tried and found very satisfactory by the Missouri River Power Co.

Protection.

To the present time no absolutely satisfactory method of lightning protection has been devised. There are several methods in use, chief of which are: horn arresters, the system of using a grounded wire, and the multiple gap arresters used in conjunction with static dischargers or static interrupters. The horn type of arresters has not as yet been used very extensively in the United States, and has not proven its worth under continuous severe lightning storms. Wherever it has been

used it has proven very satisfactory as far as protection was concerned, but there is one serious disadvantage in its use which has not been remedied, and that is the fact that it does not extinguish the arc which is caused by a discharge through it. The arc lasts sometimes for two or three minutes, and thus causes a short circuit, which necessitates a shut down of the entire system.

The system of the grounded wire has proven itself to be indispensable in some cases while in others the engineers think it is entirely impractical. There are various opinions among engineers as to the effectiveness of this method.

The adjustable multiple gap arrester is most extensively used in conjunction with choke coils, static interrupters or static dischargers. The static discharger has not proven very satisfactory and is being discarded more and more. Serious line troubles have been traced to this piece of apparatus. The best method of protection and the one which is coming more and more into prominent use, is that of using the multiple gap arrester together with a static interrupter.

Since this transmission system is of all steel construction in which the towers afford a good path to ground and are not injured by lightning strokes, the use of the grounded wire system will be omitted. The method of lightning protection to be used is that of installing at the generating and receiving stations a Westinghouse low equivalent adjustable spark gap arrester with series and shunt resistances. In

addition to this arrester will be used also the Westinghouse Static Interrupter. The arrangement of apparatus and connections is shown diagrammatically on Plate VII.

Grounds.

When the use of an iron pipe is considered advisable for the protection of a ground wire, a plug should be put in the top of the pipe and the wire soldered to it; otherwise, the reactance of the ground wire surrounded by the iron pipe will impede the discharge. Copper sheets approximately 1/16 inch thick and having at least four square feet of surface, are good forms of grounds. The ground wire which should preferably be a flexible strip with a cross section not less than that of a 3/4 inch round wire must be carefully soldered and riveted to this plate, which is then buried in powdered coke in soil which is always damp.

Dry sandy soil should be kept wet by artificial means, if this is the only soil available. In this soil it is advisable to dig several trenches radiating out from the main ground where the ground wires are buried, so as to obtain a large surface for the dissipation of the charge. Where plates are placed in streams of running or dead water, they should be buried in the mud along the bank in preference to merely laying them in streams, and streams with rocky bottoms are to be avoided except as a last resort. Where there are metal flumes, pipes, or rails, it is advisable to rivet and solder the ground wires to them in addition to the connections to the copper plates.

In view of the fact that grounds should be frequently inspected, it is advisable when the ground plates are installed to lay out exact plans of the location of the ground plates, wires and joints, with a brief description of the same so that at any future time the data may be referred to.

In laying the ground great care should be taken so that there will be no turns or kinks in the wire. The wire should be as straight as possible, because since the lightning is of very high frequency it is believed that a kink in the wire will produce enough reactance to cause the lightning to seek other paths of discharge. The path from the point where the charge of lightning is caught to the ground should be as direct and short as possible.

Transposition of power wires.

The power circuit shall be transposed twelve times at equidistant points along the entire length of the system, as shown by diagram on Plate VI. By this transposition each wire will make four complete turns between generating and distributing stations. There are prevalent among engineers various opinions as to the necessity of transposing power lines. Some think it is decidedly necessary because in their opinion it causes less interference with parallelingtelephone and telegraph wires, and the more spiralling the less will be the apparent impedance. Others think it is unnecessary and some seem to think it is unnecessary to transpose power lines as a protection to adjacent telephone and telegraph lines.

Inductance and charging current.

In papers presented by Mr. Baum before the American Institute of Electrical Engineers on May 18, 1900 and before the International Electrical Congress at St. Louis in 1904, he shows that in a three-phase, star-connected line the capacity of each line to neutral is given by the equation

$$C = \frac{1}{2 \log_{\varepsilon} \left(\frac{d}{r} \right)}$$

in which C = capacity in electrostatic units per centimeter of circuit, d = distance between wires in inches and r = radius of wires in inches.

The charging current per mile of wire is

$$I = \frac{2 \quad f \; E \; c}{\sqrt{3} \; x \; 10^{6}}$$

This reduced to more practical units gives

$$I_W = 2\pi f \frac{E}{\sqrt{3}} x \frac{.0776 \; L}{10^{6} x \; 2 \log_{10} \left(\frac{d}{r} \right)}$$

IN which I_W = charging current per wire

f = frequency

E = line voltage

L = length of transmission system in miles.

d and r = same as above.

For the self induction in C. G. S. units per centimeter for one wire of two parallel wires

$$L = 2 \left[\log_{\varepsilon} \left(\frac{d}{r} \right) + .25 \right]$$

For one loop of a three-phase system

$$L = \mathcal{L}\sqrt{3}\left[\log_{\varepsilon}\left(\frac{d}{r}\right) + .25\right]$$

which when reduced to practical units gives

$$L = .001285 \log_{10}\left(\frac{d}{r}\right) + .0000139$$

in which L = henrys per mile per loop.

By substituting in these formulae the following results are obtained:

$$I_W = \frac{2\pi \times 25 \times 60000 \times .0776 \times 160}{\sqrt{3} \times 10^6 \times 2 \log_{10}\left(\frac{78 \times 2}{.772}\right)}$$

$$= 14.6 \text{ Amperes}$$

which is the charging current per wire.

$$L = .001285 \log_{10}\left(\frac{78 \times 2}{.772}\right) + .0000139$$

$$= .0029766 \text{ henrys per mile per loop}$$

or $= .0029766 \times 160 = .047626$ henrys per loop.

Special construction.

There are two special cases of line construction which must be provided for. The first one is where the line crosses the Mississippi, and the other where the line ascends a steep hill. The river will be regarded as 1500 ft. wide and having banks on both sides that rise 15 ft. above the high water mark. A 75 ft. clearance must be provided between the

lowest point of the wire and the high water level. The hill will be regarded as being 1500 ft. long and making an angle of 60° with the horizontal.

To cross the river and mount the hill single spans of 1500 and 1800 feet respectively will be used. Because of the length of the spans, there will be heavy mechanical strains placed upon the conductor which this size of aluminum cable will not withstand without being re-enforced. Furthermore, excessively large deflections will necessarily have to be allowed when only aluminum will be used. For these reasons the spans will be crossed by the same aluminum conductor supported by a plough steel cable of 1/2 inch diameter. This cable has the following properties:

Weight per ft.	.39 lbs.
Approximate breaking strain	22500 lbs.
,Allowable strain	18000 lbs.

6 strands of 19 wire per strand.

Galvanized and wire center.

With these steel cables it is customary to allow a deflection of .02 of length of span. Considering the river span and using same formulae as before gives the following results:

$$D = 1500 \times .02 = 30 \text{ ft.}$$

$$L = 1500 + \frac{8 \times 900}{3 \times 1500} = 1502 \text{ ft.}$$

$$R_m \frac{\left[(1500)^2 - 4 \times 900\right]}{8 \times 30} \times 1.5 = 14000 \text{ lbs.}$$

$$R_E = \sqrt{(14000)^2 + \left(\frac{1500 \times 1.5}{2}\right)} = 14045 \text{ lbs.}$$

For the span going up the hill

$$D = 1800 \times .02 = 36 \text{ ft.}$$

$$L = 1800 + \frac{8 \times 36 \times 36}{3 \times 1800} = 1802$$

$$R_m = \frac{\left[(1802)^2 - (4 \times 36 \times 36)\right] \times 1.5}{8 \times 36} = 17000 \text{ lbs.}$$

$$R_E = \sqrt{(17000)^2 + \left(\frac{1802 \times 1.5}{2}\right)^2} = 17311 \text{ lbs.}$$

In both these cases the calculated strains fall below the allowable strains, and therefore this steel cable is sufficient for both spans.

The towers that support the cables which cross the river must have a height of

$$75 + 30 - 15 = 90 \text{ ft.}$$

from the ground to the lowest supporting arm and must be able to withstand a horizontal strain of

$$1502 \times 6 \times 1.5 = 13518 \text{ lbs.}$$

The telephone line instead of being spanned across the river, should be passed through lead covered cable, which should be protected by sections of iron pipe and laid across the bottom of the stream.

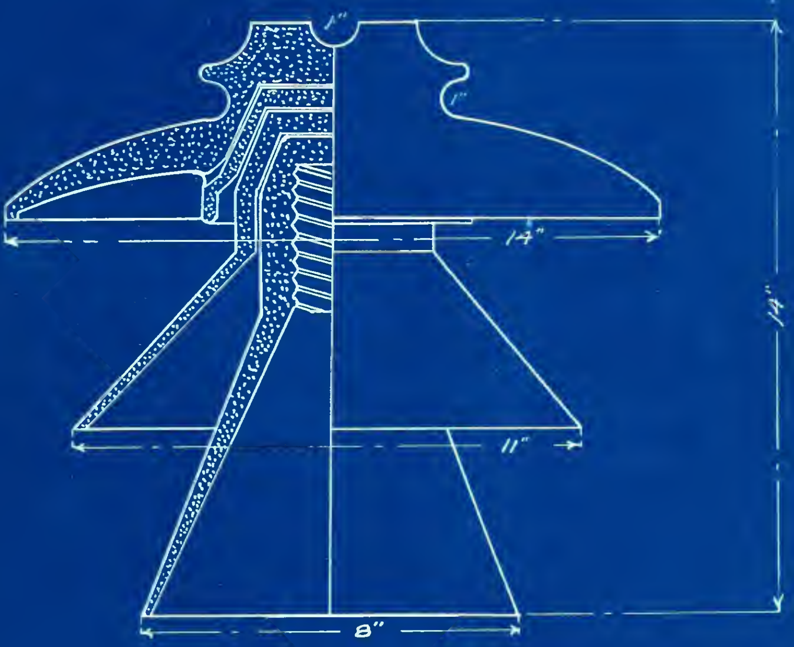
The towers supporting the 1800 ft. span of cables will need to be only 45 ft. in height from the ground to the lower cross arm. They must be able to withstand a strain of

$$1802 \times 6 \times 1.5 = 15218 \text{ lbs.}$$

in a line making an angle of 46 15' with the horizontal. The upper tower shall be set at the edge of the top of the hill and the lower one 980 ft. from the foot of the hill. Through this span the telephone wires should be supported by a separate pole line.

The towers supporting both the 1800 and 1500 ft. spans should necessarily be set in heavy concrete foundations. In both cases both the aluminum and steel cable of each string should be supported at the towers by a series of nine line insulators and the pins fastened to a longitudinal arm hinged at one end to the tower to permitted adjustment to span motion. This arm is shown in drawing on Plate VIII.

INSULATOR



SCALE 4" = 1'

BROWN GLAZED PORCELAIN

PLATE I.

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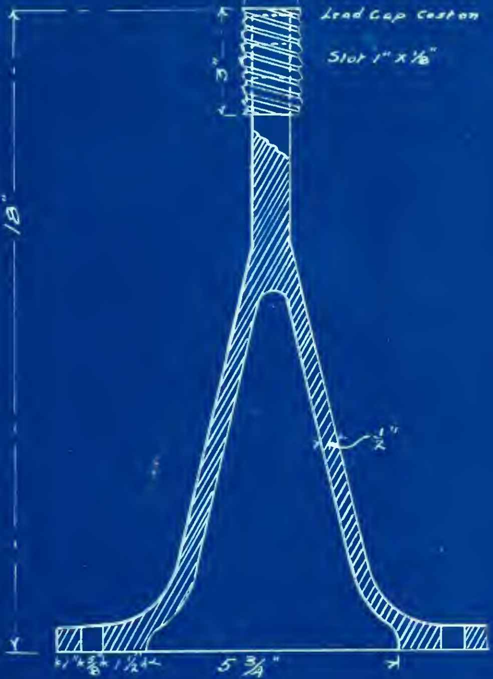
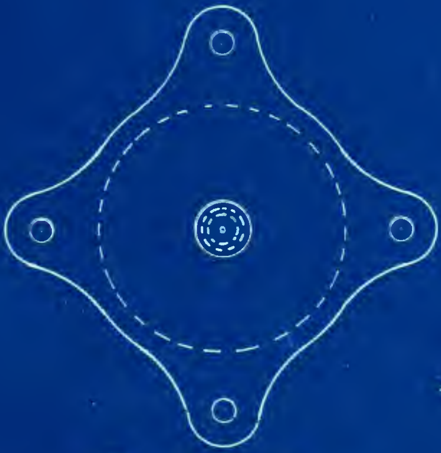
MALEABLE IRON INSULATOR PIN





Scale 3"-1'

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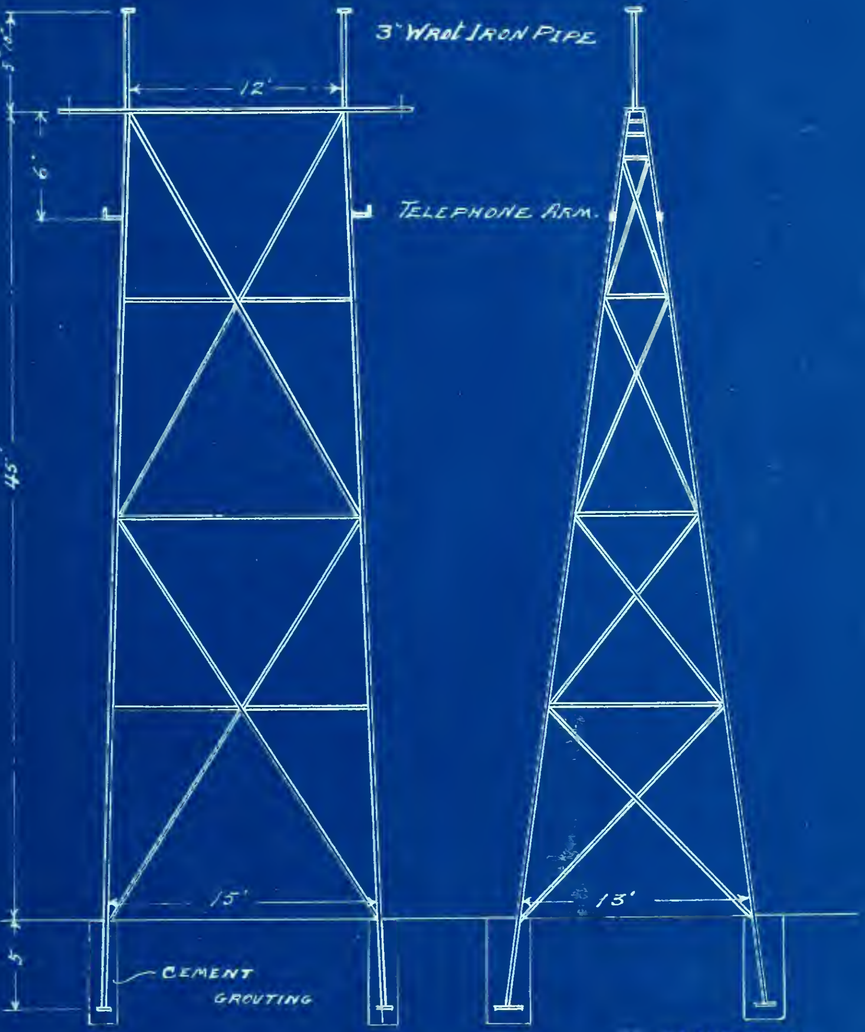
PLATE II.

GENERAL TYPE OF TOWER



SCALE 8'=1"

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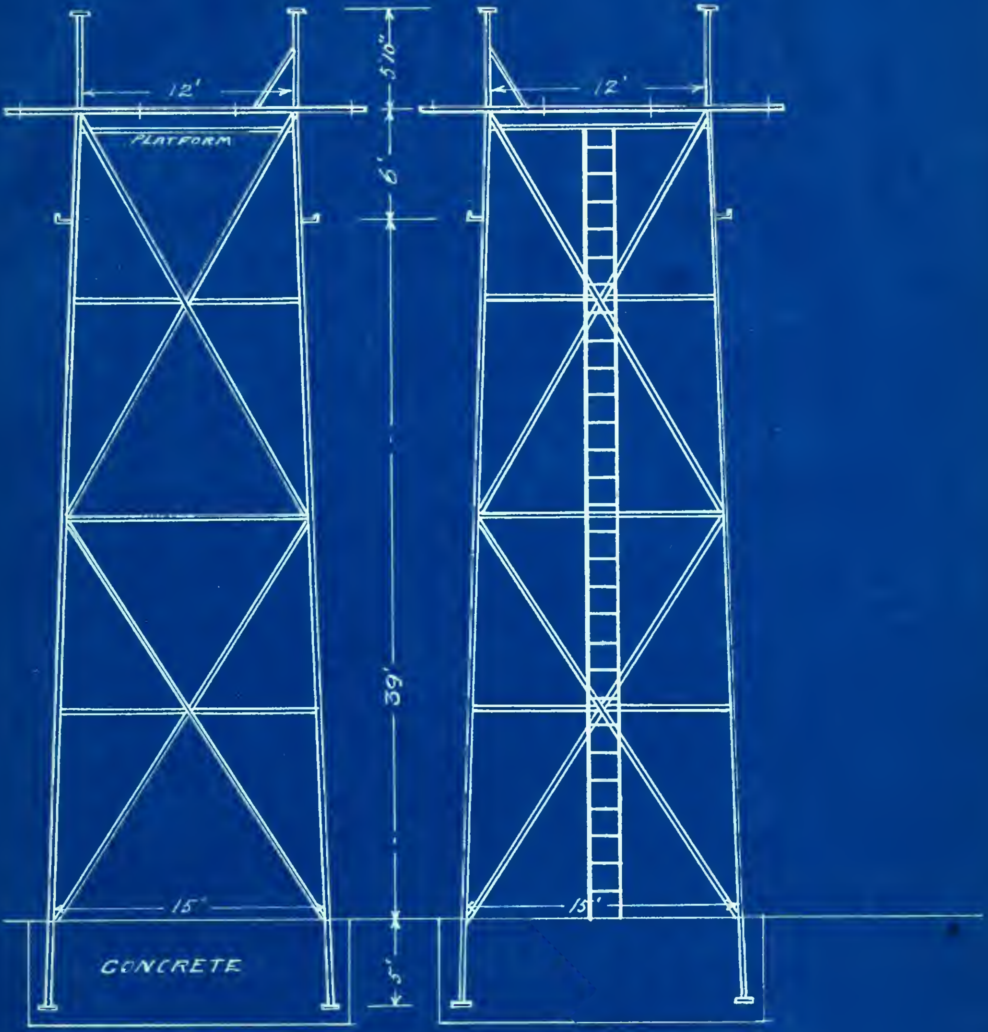
PLATE III

TOWER USED AT A 90° TURN IN LINE



FRONT

SIDE

SCALE 1/8" = 1'

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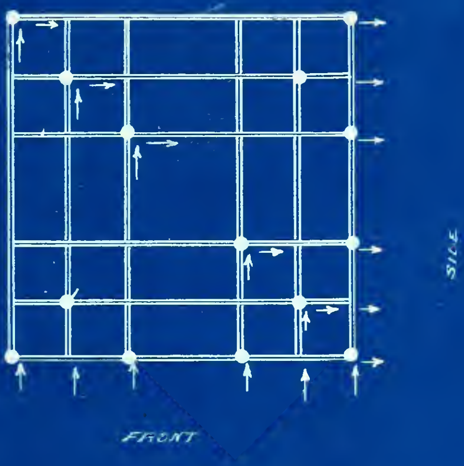
PLATE IV

TOP VIEW OF CORNER TOWER
SHOWING
SCHEME OF MAKING TURN.



HEAVY DOTS INDICATE POSITION OF INSULATORS

ARROWS INDICATE DIRECTION OF WIRES

SCALE ⅛" = 1'
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PLATE V

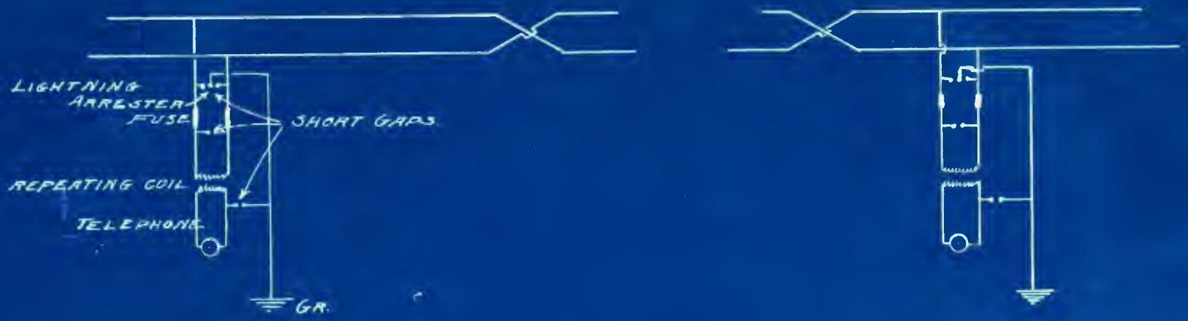

DIAGRAM OF TELEPHONE CONNECTIONS.

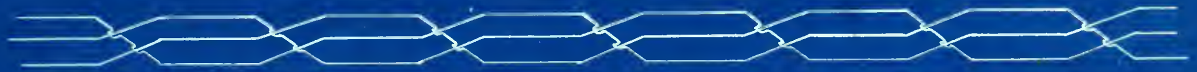

DIAGRAM OF TRANSPOSITION OF POWER WIRES.

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PLATE VI.

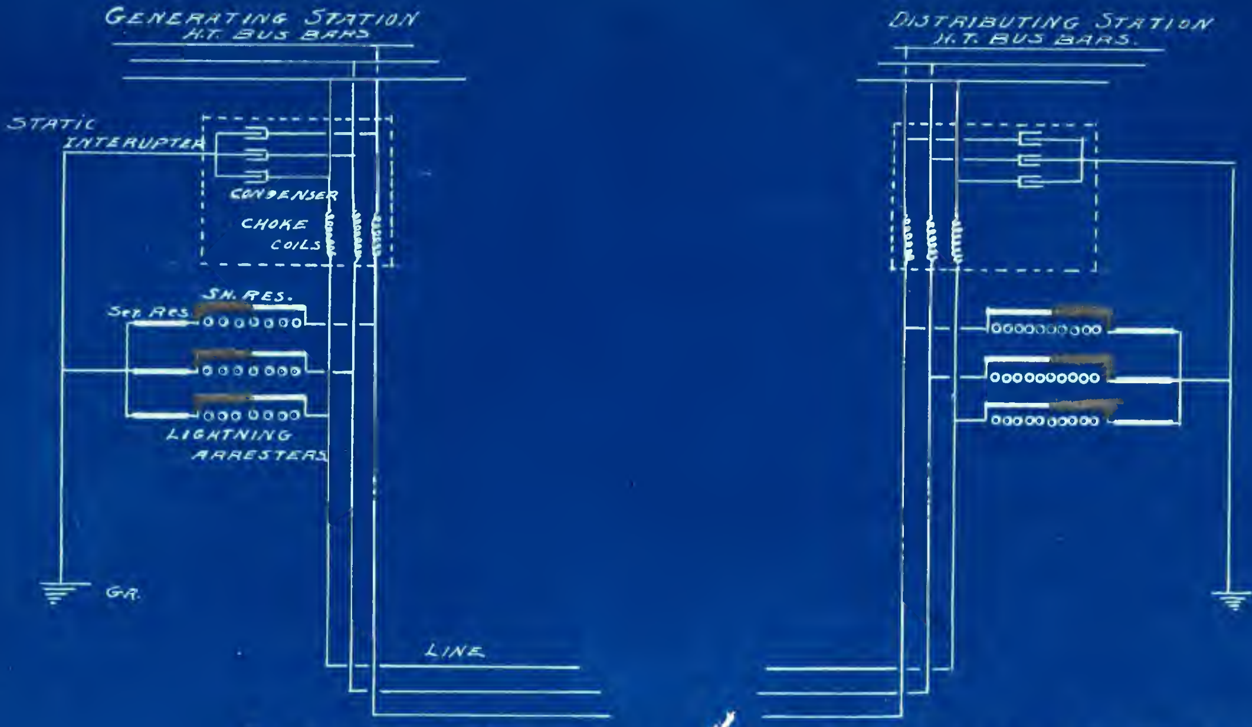

DIAGRAM OF CONNECTIONS OF PROTECTIVE APPARATUS

PLATE VII

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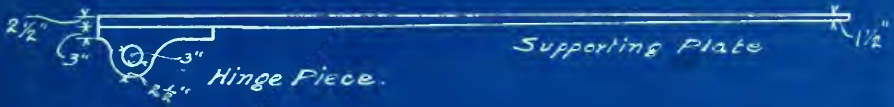
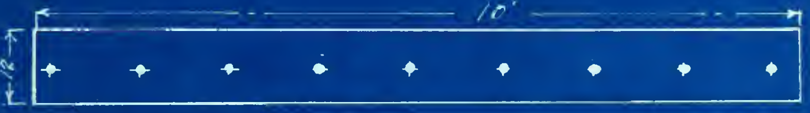
ARM FOR SUPPORTING CABLE IN 1800 & 1500 FT. SPANS





Heavy Dots Indicate Position of InsuLators.

Cable is To Be Fastened To Each Insulator In Series

Hinge Piece to be Bolted to Supporting Plate

Arm is then to be hinged to Supporting Tower

Scale 25" = 1"

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PLATE VIII